PSYCHOLOGICAL LITERATURE.

I.—NERVOUS SYSTEM.

Report of six lectures on cerebral localization, delivered in Boston, by DR. HENRY H. DONALDSON, before the Boston Medico-Psychological Society, February and March, 1891. From notes by T. L. Bolton.

It was the aim of these lectures to show the bearing of the more recent anatomical investigations on the question of cerebral localization, rather than to give a full account of the subject.

LECTURE I.

Gentlemen:—I shall open this course with a statement of some recent advances in our knowledge concerning the structure of nerve cells and nerve fibers, and the relation of these to one another. The advance has come about by the introduction of a new method, which is due to the Italian histologist, Golgi.[1] To the labors of Golgi and his Spanish pupil, Ramon y Cajal,[2] is due the discovery of the most important points which are to be described. As everything depends upon the validity of the method employed, I will briefly state its essential character. The method of Golgi outlines the nerve cell and its prolongations by means of a deposit or precipitate which is formed just outside of these structures, and occupies the lymph space which surrounds them. The deposit is an inorganic precipitate of a silver or mercury salt, and forms a dense incrustation about the nerve elements. Further details are not necessary here. The result of this reaction is to outline the nerve elements in black on a light background. The inference is that, where this incrustation goes there goes a prolongation of the cell. On this assumption, which appears in the main well founded, depends the entire significance of the method. Golgi's first result was that the axis-cylinder process from the nerve cells was branched. Closer examination of axis-cylinder processes indicated that they might be grouped in two classes; first, those in which the branching was not sufficient to obscure the identity of the main prolongation; second, those in which the main prolongation divided into many branches soon after leaving the cell, and thus lost its identity and faded out. In the dorsal cornua and in the so-called sensory regions of the cerebral hemispheres, this second type of cells was found whereas the first type appeared in the ventral cornua of the cord, and in non-sensory portions of the cortex. From this general distribution, Golgi was led to designate the cells of the first type as motor and those of the second as sensory. To the axis-cylinder of the second type Ramon has added some very suggestive details in that he finds the smallest branches of these prolongations surrounding in certain cases cells, *e. g.*, the cells of Purkinje in the cerebellum, and enclosing them like a basket. This manner of termination of the ultimate branches of the axis-cylinder appears particularly well developed in the instance cited, but it furthermore appears to be the usual manner in which such branches end when they terminate in the neighborhood of nerve cells.

Besides the prolongations which come from nerve cells lying within

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1 Golgi : Sulla Fina Anatomia degli Organi Centrale del Sistema Nervoso, 1886.
2 A. Kölliker, Zeitschr f. Wissen, Zool. Band 49 u. 51.

the central nervous system, the dorsal cornua of the spinal cord are filled with a mesh-work of a similar character, which is due to a breaking up of the axis-cylinders of the dorsal roots. All the sensory fibers of the central system appear to come from the spinal ganglia or homologous structures,—the fibers of the optic nerve are alone the possible exceptions to this rule. It will be seen from this arrangement that the sensory cell of the older histologists—meaning, thereby, a cell situated in the dorsal cornua and sending an axis-cylinder through the dorsal nerve roots to the periphery—finds no place. It has, therefore, been thought best to modify the terminology so that by sensory cells are meant those forming the spinal ganglia and giving origin—directly to the sensory fibers. Motor, or efferent, is the terms retained for Golgi's cells of the first type; but the cells of the second type, which he termed sensory, are perhaps better designated as central.

While our interest has been specially attracted to the axis-cylinder process, it may be well to point out that the protoplasmic prolongations of the nerve cells have been brought out by this method with unusual distinctness and detail, and since they cannot be seen to unite with one another nor to give rise to nerve fibers, the question has been raised concerning their function, and the general conclusion is that they must be looked upon as nutritive. I wish for a moment to leave the nerve cell and to take up some recent results relating to the histology of nerve fibers. We have in the medullated nerve fiber an axis-cylinder surrounded by a sheath of somewhat complex structure. The axis-cylinder is the portion of the fiber which interests us at this moment. There are, roughly speaking, two views concerning its structure. One which has been ably advocated by Nansen[1] looks upon the axis-cylinder as a mesh-work, in the cavities of which is to be found a plasma, and this plasma is the active substance in process of conduction. The second view, which has recently been elaborated by Boveri,[2] considers the axis-cylinders as made up of a number of fibrillæ floating in a plasma. These fibrillæ are considered as unbranched and as continuous from the nerve cell to the termination of the axis-cylinder process to which the cell gives rise. If we look upon the axis-cylinder prolongation as made up of these fibrillæ, then the branching of the axis-cylinder is to be interpreted as the giving off of small bundles of fibrillæ. In considering the manner in which the nerve fibers arise from the nerve cell, I may allude to the recent observations of His[3] on the development of the spinal ganglia in man, which show that the well-known T process of Ranvier, by which the cells of the spinal ganglia are joined with the nerve fiber, is a derived structure. These cells originate as bipolar nerve cells, similar to such as are found in lower vertebrates. In the course of development, however, the two poles from which the nerve fibers originate gradually approach and finally fuse with one another, thus giving rise to the stem of the T, one branch of which runs centrally and the other toward the periphery. In the hands of Ramon the methods of Golgi applied to fœtal, or very young animals, in which the nerve fibers were only in part medullated, has developed some startling results concerning the branches of nerve fibers. The net work which Golgi observed in the dorsal cornua of the spinal cord was the final termination of the dorsal root fibers. Ramon has now shown that as soon as the fiber enters the cord it divides into two branches, one running cephalad, the other caudad. That these two branches give off further, branches at right angles to their course, which have been called collateral fibers, and that it is the termination of these collaterals which gives use to the mesh-work already men-

1 The structure of the Histological Elements of the Central Nervous System. Bergen, 1887.
2 Abhandl. d. k. bayer. d. Akademie. Wissen, Band XV, 1885.
3 Archiv. f. Anat. u. Physiol., 1890.

tioned. These collaterals, however, are not confined to this group of fibers alone, but, as it appears, may be found arising from fibers in almost any part of the cord. This rather startling result is difficult to explain, if we consider that the medullary sheath of the medullated fibers in the cord is unbroken throughout its extent. The recent observations of Porter[1] show, however, that there are nodes of Ranvier in these fibers in the spinal cord, and, although we know nothing of these nodes further than their probable existence, they would seem to offer a convenient point of departure for the collateral fibers and thus bring the law of branching in the central system into harmony with that for the peripheral nerves, where the branches occur at a node of Ranvier.

There is one principal point which has thus far been left out of the discussion, viz.: how far are the fibers which are brought out by this method of Golgi to be identified with the medullated fibers with which we are commonly familiar? It seems beyond doubt that a number of the structures thus developed are unmedullated even in the adult. One important piece of evidence has been presented by Flechsig[2]. He has succeeded in staining specimens of nerve cells, which had been previously treated by Golgi's method, with a dye stuff which stained medullary substance red. According to this result he finds many of the branches of the axis-cylinder process to be medullated, and thus it would appear that these branches may become medullated nerve fibers.

We come now to the final point of the connection between nerve cells and nerve fibers. Of course each nerve fiber is looked upon as the outgrowth of a certain nerve cell, and the connection referred to in this instance is that between the termination of a nerve fiber and neighboring nerve cells with which it may be supposed to be physiologically associated. The connection of the nerve cells with one another is but another aspect of the same problem. It may be stated as a general result that this method fails to show any direct continuity between any prolongations of one nerve cell and those of another. This lack of demonstrable continuity has led to several hypotheses; the best of which is perhaps that of His, who points out that, however closely the protoplasmic prolongations may be interwoven, there is always a somewhat between them which we are accustomed to designate as ground substance, and to this ground substance must be attributed the function of establishing continuity between the nervous elements. The earlier workers in this line had directed their attention to the remarkable branches of the axis-cylinder prolongations, and thought in some way these would account for the physiological connections between cells. At present, however, there is no positive evidence in favor of such a view.

Taking a general view of the nervous system, we find the sensory impulse coming in through the dorsal roots which form a mesh work in all probability connecting, as a rule, with some of the central cells, and thus finding its way to the higher centers, or perhaps without the intermediation of central cells, reaching the efferent cells in the ventral cornua. Nansen, who wrote a few years since and was much impressed with the possibilities of the network formed by the prolongations of the axis-cylinder, drew up a scheme which I believe has been received with some favor, according to which the nervous and mental process were considered as taking place in this mesh work, while the cells were regarded as having a nutritive function and acting as the supporters of the mesh work alone. It now remains to point out some of the peculiarities of our point of view as determined by these results. I will give them in briefest form possible. The new methods show that the axis-cylinder is branched; that there are several types of axis-cylinders; that these branches may become medullated, hence several fibers may

1 Quart. Journ. Micros. Sci. Feb. 1890.
2 Archiv. f. Anat. u. Physiol. 1889.

arise from one cell; that there are no sensory cells in the central system; that the axis cylinders are made up of fibrillæ; that nodes of Ranvier occur within the central system; that collateral fibers arise from the longitudinal fibers of the spinal cord; that no nerve fibers come from the proto-plasmic process; and that there is no continuity between cell elements in the central system, but that probably physiological connection is dependent upon peculiarities of the ground substance which surrounds them all.

LECTURE II.

Gentlemen: This lecture will be a continuation of the preceding upon the architecture of the nervous system. I shall consider the size of the nervous elements, their numerical relations, the relation of the cerebral cortex to the optic thalamus, and say a few words upon some methods of ascertaining the localization of functions in the central nervous system. Nervous elements differ much in size. In speaking of the size of the nervous elements, one point should be emphasized. Nerve cells and fibers are in reality but parts of the same structure; the fiber is a branch of the cell. The nervous system must, therefore, be considered as composed of one kind of elements—the cells. There is a relation between the size of the cells and that of the fibers, more especially between the nucleus of the cells and the fibers.[1] The nerve fiber is composed of a sheath and an axis-cylinder. This axis-cylinder is made up of a number of minute fibers known as fibrillæ. The branching of a nerve is simply the separation from the main axis of a number of fibrillæ surrounded by a continuation of the sheath. All nerves terminate finally in a mesh-work of the fibrillæ. If we examine the ischiadic nerve of a frog, we find it to be conical in shape. Transverse sections of the nerve at the hip, the knee and the ankle, show a diminution in the diameter of the individual nerve fibers, as we proceed from hip to ankle. The old explanation for this was that the fibers themselves were conical in shape; but this is probably incorrect. The diminution in diameter is really due to the fact that the nerve trunk branches and the branches from the higher levels contain the fibers of greatest diameter, and those from lower levels contain those of smaller diameter. The physiological bearing of this is important. Suppose the proximal muscles of a limb to be as richly supplied with nerve fibrillæ as the distal muscles are, then since we have found that nerve fibers of large diameter supply the proximal muscles, it follows that in order to have the same abundance of fibrillæ for the distal muscles, that the individual nerve fibers supplying them must be more numerous. Here let us depart from the main point for a moment in order to bring up a subject necessary to make clear the explanation that follows. Every motor cell, so far as is known, acts as a unite and give rise to but a single motor fiber. Thus, whenever a discharge occurs in the cells, the muscle in which the fiber terminates must respond. If, however, a muscle be the termination of several fibers, several cells control its action and thus a finer control is brought about. The significance of size of nerve fibers is usually stated to be that the larger fibers run the longer course, for larger fibers are necessary to carry the nervous impulses to greater distances, on the analogy of electricity where the larger wire is the better conductor. The largest fibers in the frog arise from the lumbar region of the spinal cord and terminate in proximal muscles. The differentiation of function is slighest here, and fineness of adjustment is least needed. From this we conclude that large fibers are concerned with coarse adjustments, and fine fibers with fine adjustments. We turn now to consider what is known of the

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[1] Mason ; Journ. of Nervous and Mental Disease, 1880, 81,-82.

numerical relations within the central nervous system. Birge,[1] working with Gaule, undertook an actual count of the number of the fibers entering the spinal cord by the anterior and posterior nerve roots. This actual number of motor fibers determined by the count corresponded very closely with the number of cells in the ventral cornua of the spinal cord. From this a munerical equivalence between motor cells and motor fibers was inferred. Gaule[1] has carried the investigation a step further by counting the number of nerve fibers in cross sections of the spinal cord at five different levels and has then attempted to determine whether there was any relation between the number of fibers of these various levels and the number of the dorsal root fibers entering the cord at the same levels. He finds as a result that each root fiber calls for eleven fibers in the cross section. Thus there appears to be a distinct numerical relation in this instance. It should be remembered that Gaule is dealing with medullated fibers only and whatever relations may be dependent upon unmedullated fibers do not enter into his calculations.

In his paper, upon this subject, Gaule has a system of philosophy which is peculiarly his own.

It may be roughly stated as follows : As the cells are composed of molecules which are made up of atoms standing in a fixed and definite relation to one another, so the body is composed of cells which appear in fixed proportion, for instance every sensory fiber demands eleven nerve fibers in a cross section of the cord.

Charts of the brain have been made by several authors for the purpose of showing the various developments of the cerebrum. Broca, Obersteiner, Eberstaller and Wilder have constructed such charts as you see, according, as it was their purpose to illustrate particular points. The need for some definite diagram on which to plot lesions useful for the localization of function has been felt. For this purpose the best of these perhaps is that of Eberstaller, which was designed to show almost every detail, while that of Wilder brings out the early developed characteristics mainly. The amount of variation that may occur in the central nervous system is very great. All brains differ. Several attempts have been made to measure the extent of the gray substance of the hemispheres. The figures vary between 1800—2700 sq. cm. The important relation is that the sunken gray matter lying in the sulci is about twice that which is exposed on the surface. Suppose that in brains which are comparable, the sulci have a similar depth and the nerve elements a similar size, then a richly convoluted brain would contain a greater expanse of gray matter, and a greater number of cells would be found in such a brain. The converse would be true ; a poorly convoluted brain would contain a less expanse of gray matter and a less number of cells. If, as Gaule asserts, every nerve cell gives rise to a definite number of fibers and the amount of branching be similar in cases compared, that brain which contains the most cells, has the most branches. These branches become medullated fibers and constitute the white substance. According as the number of cells is greater, and hence the number of fibers large, the amount of white substance will be great and the size of the brain increased. However, Gaule's numerical relation is probably only partly true. All of us are acquainted with large brains that are poorly convoluted, and the preceding remarks on the relation of the size of the cerebrum to the abundances of their convolutions have for their main purpose to direct attention to the compensatory developments which probably occur there, but about which we know almost nothing.

1 Archiv. f. Anat. u. Physiol., 1882.
2 Abhandl. d. König. Sächs. Gesell. d. Wissens. B. XV, 1889.

Such a scheme as that of Gaule at once raises the question, how far variation may occur within the nervous system. We have there many decussations, such as that of the optic tracts, of the cranial nerves and of the pyramids. Variations in these decussations are known to all. Our physiological inferences are based upon anatomy. If the anatomical foundation can vary, it is a most important point, especially in the case of the nervous system, and one which must always be kept in mind, when physiology and anatomy appear to conflict.

It may be possible sometime to track a sensory nervous impulse from the periphery to the contex. All of us have been taught that sensory fibers enter the spinal cord by the dorsal roots, and proceed by the dorsal columns towards the brain, and terminates in the ganglia of these columns. From these ganglia they pass to the thalamus of the opposite side, by way of the lemniscus. The cells of the thalamus are connected with the cells of the cortex by the fibers of the corona. There is some reason to think that whatever the source of the sensory impulse, it must pass through the thalamus before going to the cortex. Several attempts have been made to determine the relation between the portions of the cerebral cortex and the thalamus.

Monakow[1] determined this relation in rabbits. He operated on the dorsal and lateral surface of the hemispheres only. Here the removal of definite portions of the cortex caused an atrophy in an equally definite portion of the thalamus. There were certain portions of the thalamsus, which were not affected by any of the lesions and these by exclusion may be supposed to be connected with those portions of the cortex which were never injured. These results have been in part verified for man.

LECTURE III.

Gentlemen : We shall consider in this lecture the motor regions of the brain. The middle portions of both hemispheres contain motor centres. A history of the subject is not needed; but the method used for the discovery of these centres and of the refinement of their subdivisions deserves some attention. Our especial interest is in the subdivisions. Motor is not a good term to apply to this region, but it is the best we have. The idea of the motor centres from an anatomical point of view is useful. The central nervous system may be considered as a conical mass with the cortical centres in the base of the cone, the apex of the cone representing the spinal cord. A nervous impulse proceeds from the periphery toward the cortical centres and at various levels in the cone it encounters masses of gray matter which increase the possible number of paths the impulse may take. The important question then is: Does the impulse diffuse itself throughout the entire system or follow a fixed path to a definite centre in the cortex? The possible paths depend upon the complication of the central system. In higher animals, the possibilities are many. The paths followed in any given case depend upon physiology rather than upon anatomy. The path of the impulse appears to be simple; it starts from a small area in the periphery and reaches a small area in the cortex. The cortical centre is but a specific point in the path of the impulse, where the impulse turns to pass centrifugally. As points in the path of an impulse the cortical centres are like innumerable other points in the central system, but they have a peculiar interest because of their great accessibility and because they are in a region which is supposed to be associated with mental phenomena.

Let us now consider the method of stimulating the cortical centres. Horsley[2] attempted to determine whether all the parts of the muscle

1 Arch. f. Psychiatrie B. XII, 1882.
2 Gotch and Horsley—Proc. Roy. Soc. London, 1888, XLV.

curve given by a muscle during an epileptic seizure, were due to the cortex alone or to cells lying outside of the cortex. He exposed the brain of a monkey and found the area for the control of the leg. An electric current was applied and an impulse sent to the spinal cord. By tapping the spinal cord in the dorsal portion and recording the impulses passing there in the pyramidal tract, by means of an electrometer, both the tonic and clonic portions of the curve were shown to be due to the impulse from the cortex. Others have observed that when the cortex was excised, and the stimulus applied directly to the nerve fibers, the clonic portion of the curve dropped out. This fact has been used clinically. Horsley has studied the minute representations in the cortex of movements of the head and limbs. His method was to apply to the cortex electrodes, two mm. apart, with a current just sufficiently strong to bring about a contraction. The strength of the current was important; a weak current would contract few muscles slightly and a stronger one would cause a stronger contraction of a greater number of muscles. To explain this contraction in the last case a slight irradiation of the stimulus was supposed to take place, so that neighboring centres were involved. The diagrams show the results of Horsley's experiments. The outline of the region enclosing the motor areas is largely bounded by fissures—below by the Sylvian fissure, behind by the inter-parietal, in front it passes somewhat in front of the praecentral, and above the margin of the hemisphere forms the boundary from this point of view. There is no necessary connection between areas and sulci; some areas appear to be limited by sulci, and others not. The portion of the cortex lying in the sulci is one that usually escapes stimulation.

In the motor region of the monkey's brain the motor areas for the control of the various parts of the body were found to be located thus: The head and eye area is located in the front part of the motor region; above the Sylvian fissure is an area for the control of the larynx, pharynx, and the movements of the mouth and face; back of the head area and above that for the face is an area for the upper limb; still back and above this is an area for the control of the lower limb; and between the areas for the upper and lower limbs is one for the trunk. It will be noticed that we thus pass in serial order through the centres for the head, arm, trunk and leg, the first most anterior and the last most posterior. The same serial arrangement is maintained on the mesal surface. There is a remarkable independence between the size of the centres and the mucles they control. The centres controlling the head and face constitute about half the motor region. Where the muscles are large and the movements crude, the representation in the cortex is small. The area for the head has been longest undergoing differentiation; next to this in order of development is that for the upper limb, that for the lower limb, and lastly for the trunk. Beevor and Horsley[1] have studied in detail the anatomy of these areas, especially that of the arm, and have found there is a subdivision of function within them. They divided the area of the arm into squares of 2 mm. on a side and stimulated these squares in regular order. Attention was given to what movements came out first—the so-called primary movements. The first movement following a given stimulus in the uppermost part of the arm area was the movement of the shoulder; when the stimulus was applied a little lower down, a movement of the elbow took place; it was then applied further down still, and a movement of the wrist was the result; when however, the stimulus was applied to the lowermost part of the arm area, the thumb responded. The centres for the control of the shoulder and the thumb are then farthest separated. The thumb is the most highly modified portions of the upper limb, and its movement is

1 Beevor and Horsley—Phil. Trans. Roy. Soc. London, 1887, 1888.

the most highly modified movement. The opposition of the thumb is very widely represented. It was determined that in general the march of a spasm affecting the arm follows the order of the centres within the arm area; that is, if the spasm starts at the shoulder, it passes by regular progression to the fingers, or if it starts in the thumb, it passes in regular progression along the limb in the opposite direction. It appears, however, that the connection between the thumb and shoulder is very slight, so that a spasm starting in the shoulder does not usually terminate in the thumb, nor does one commencing in the thumb, terminate in the shoulder. Looked at from one point of view this would appear to indicate that the association tracts in such an area were short, and, as a rule did not extend beyond the nearest lying centre.

No centre will give a particular movement exclusively, but certain movements usually follow stimulation in a definite portion. The subdivision of function in other areas was studied by these same authors. They endeavored to determine the kind of motion resulting from stimulation. They found that extension of the arm followed stimulation in the upper portion of the arm area, flexion in the lower portion, and that there was a confusion of movement, when the stimulus was applied to the central portion of the area. Extension and flexion in all centres are usually widely represented. Let us carry these facts over to the diagram of the mesal surface of the human brain[1]. The localization of functions on the mesal surface appears in the order of head, arm, trunk and leg from before backwards. The basis for the schematic representation in man is about as follows: some of it is based upon analogy and some on the results of direct stimulation. Below and behind the head and eyes there is an area for the control of the face. The localization of the face area is based primarily upon pathological and clinical evidence and secondly upon analogy with some experimental evidence for its support. The face area can be broken up into a number of other centres. The muscles concerned in speech are represented in this area. The speech centre appears to be a duplication of this representation in a refined form and is usually left out of the discussion of motor centres. It is, however, a motor centre, having fibers which pass into the internal capsule. We know nothing of the subdivisions in it. Has this motor region other than motor functions? Motor reactions follow the stimulation of the cortex outside of what is generally designated as the motor region. Stimulation in the occipital region and in the tip of the temporal lobe gave motor reactions. When the stimulus was applied to the tip of the temporal lobe, reactions in the mouth and nose followed. Movements of the eyes were to be obtained by stimulation of the head area and also of the occipital region of the cortex. These motor reactions were due, according to Ferrier, to the stimulation of the sensory cells in the cortex which in turn reacted so as to bring about movements. Schäfer[2] carried the investigation further.

When he applied the stimulus to the occipital portion of the cortex and produced movements of the head and eyes, he observed that the reaction time was longer, than when the stimulus was applied directly to the head area. By cutting out the proper centre in the head area and then stimulating the occipital portion, reaction was still obtained, which showed that motion in this case was independent of centres in this area. This is but one example of apparent multiple representation of movement in the cortex.

LECTURE IV.

Gentlemen: We shall consider this evening the sensory centres. The motor centres form a dividing line in the cortex, behind which

1 Mills. Trans. Cong. Am. Phys. and Surgeons, 1888.
2 Schäfer: Internat. Monatschr. f. Anat. u. Physiol. Leipz., 1888.

lie the sensory centres, and in front is an unoccupied area which is left out of the discussion. The anatomy of the sensory region needs some attention. If we section the white matter in the motor region, degeneration follows both toward the thalamus and toward the cortical cells. The same holds for the sensory region. These fibers are, therefore, arranged to carry impulses both ways, that is, there are both afferent and efferent fibers. Ferrier began the study of the sensory centres. By stimulating the sensory centres he was able to produce motion, but the motion was particularly associated with the peripheral sense organs. Permit me to call attention to a peculiarity of the sensory region. In the lower animals sensation is not so accurately located as motion. The reactions we have to study are crude. Slight loss of sensation can not be shown. The results of the study are often contradictory and no reconciliation seems at times possible. All the results that are accumulated are not of equal value. I shall make use of some of those results which appear most trustworthy. When one set of experiments support a view with good positive evidence, and the opposite view is sustained by equally good positive evidence, there is reason to think that a further extension of the hypothesis will harmonize the views.

Let us take up first the cortical centres for vision. The experiments have been made upon monkeys. In them we have the occipital lobe and the angular gyrus as cortical centres for vision. In man the cuneus is supposed to be connected with vision. The discussion that has taken place has been concerned with the relative values of the occipital lobe and the angular gyrus as centres for vision. The evidence is this: Brown and Schäfer[1] removed the occipital lobe on the left side and the result was a defect of vision in the left halves of the two retinae. This result was persistent, no recovery of vision occurred. They then removed the occipital lobes on both sides and complete blindness resulted. Again the results were permanent. Ferrier criticises this on the ground that they injured the angular gyrus. Brown and Schäfer removed the angular gyrus on one side and no permanent defect of vision followed ; even when they removed it upon both sides, the defect was not permanent. The criticism that is made here is that they gave attention simply to permanent defects. The removal of the angular gyrus caused transient blindness in the opposite eye. The animal could see objects afar off but could not see them so well near to, and this was apparently a persistent symptom. Ferrier[2] removed the occipital lobe and found no disturbance of vision on either side. However he left the ventral portion of the lobe intact and this is used as an argument against his results. When he removed the angular gyrus, the opposite eye was affected transciently ; but vision returned after a time. When the other gyrus was removed, the other eye was very much affected, and the eye upon the same side slightly so. He did not get a blind monkey from his operations upon either the angular gyrus or the occipital lobes alone. When he removed both the occipital lobes and angular gyri, his monkey became permanently blind. The removal of the occipital lobe from which he got little or no effect, and of the angular gyrus from which he got transient effects, when each was removed separately, gave permanent and real blindness, when removed together (!). Transient symptoms in lower animals may become permanent in higher animals. Becterew[3] has published an account of his experiments upon dogs and rabbits. With the removal of the occipital lobe, hemiopia occurred . The removal of the angular gyrus produced amblyopia in the opposite eye. We pass now to the clinical evidence in man. The region of the cuneus is usual-

1 Phil. Trans. Roy. Soc. London, 1888.
2 Lancet. June and July, 1890.
3 Neurologische Centralblatt, No. 8, 1890.

ly described as the principal centre of vision. Reported lesions mainly occur in the apex of the cuneus and extend from the occipital lobe into the angular and supra-marginal gyri. Hemiopia follows lesions in the occipital lobe. In the neighborhood of the angular gyrus, lesion produces crossed amblyopia. The same relations hold in man as in monkeys. Some subdivision of the optic centre has been made out. If the lower portion of the occipital lobe in the monkey be stimulated an upward movement of the eyes is produced. Stimulation in the middle portion causes lateral movements and in the uppermost portion downward movements. (Schäfer[1]) This has been interpreted to mean a detailed projection of the retinae upon the cortex. A partial decussation of the optic tracts would account for the location of half of each retina in each occipital lobe. Some clinical evidence for sub-division in man has been presented (Hun. Amer. Jour. Med. Sci. Jan., 1887.), but is at present insufficient.

Among birds a partial decussation of optic tracts has not been observed anatomically. In owls, however, it would seem to occur. Ferrier found that when the occipital lobe was removed, the eye of the opposite side became blind to tests applied. For purposes of experiment the sound eye was first completely bandaged; it was next enucleated, when the blind (?) eye showed enough sensitiveness to enable the bird to catch a mouse in its cage. It would appear that the small sensation here was inhibited by the simple presence of the sound eye. The inference then is that there is a partial decussation in this bird. From our present point of view, hemiopia is dependent upon partial decussation and partial decussation must be supposed to exist, when hemiopia occurs. We now pass to the auditory sense and its location. Here the positions held by the experimenters are at present irreconcilable. Ferrier stimulated the posterior portion of the superior temporal gyrus in monkeys and got a movement of the ear. Excision of this gyrus produced deafness, when the excision was made upon both sides. Brown and Schäfer removed this region and deafness did not follow. In man the clinical evidence favors Ferrier. There are two cases at least where lesion in the posterior portion of the superior temporal gyri caused complete deafness in man. In the auditory form of aphasia this region is undoubted the auditory centre.

Taste and smell are of but little importance in this connection. In this case stimulation indicated the tip of the temporal lobe as their probable centres. If, as we suppose, the discriminative use of an organ determines its representation in the cortex, these centres would then have small cortical representation. The same disagreement exists here among the investigators. Ferrier finds lesions here to produce a loss of taste and smell; Brown and Schäfer find the opposite results. Let us consider now the cutaneous sensibility, and here experimentalists are in accord upon the main issue. Ferrier produced a disturbance of cutaneous sensations by the removal of the hippocampal gyri. Horsley and Schäfer[2] followed up these results and removed the gyrus fornicatus in monkeys, when hemi-anæsthesia of the opposite side of the body followed. Partial removal was tried, but the disturbance of sensibility to pain and tactile stimuli for different segments of the body was not localized. This cortical centre appears to be connected, mainly, but not entirely with the opposite side of the body. The symptoms of allochiria followed lesion on one side. The animals thus operated upon appeared to recover after a time. The degeneration following this lesion in monkeys has been studied very carefully by France.[3] In the internal capsule it could not be definitely located, but in the crura and the pyramidal tracts the location was clear-

1 Proc. Roy. Soc. London, Vol. 43, 1888.
2 Phil. Trans. Roy. Soc. London, 1888.
3 Phil. Trans. Roy. Soc. London, 1889.

ly made out. The important point here is the degeneration of sensory fibers downward, and their presence in the pyramidal tracts in the cord and further the observation that they occupy a definite position in these tracts. France appears to have guarded against any confusion of the lesion described with the lesions following injury to motor centres. Nothing can be said at present of the frontal and ventral portions of the cortex, so we next pass to the localization of lesions in aphasia. Starr[1] gives three periods in the development of our knowledge of aphasia. The first is that of Broca-motor asphasia—the second, that of Wernicke—sensory aphasia—and the third, that of Charcot—a further analysis of sensory aphasia. According to Charcot the idea of an object for the educated man is dependent upon two sensory centres—auditory and visual, and is capable of expression either by the spoken or written word. We have then four principal centres to consider. In visual and auditory aphasia lesions occupy definite areas. For motor aphasia the motor centre is the speech centre. Sensory lesions occur mainly in the region behind the fissure of Sylvius; auditory disturbances being associated with lesions of the superior temporal gyrus, and visual disturbance with these of the angular gyrus. Where the motor centre for writing may be, is not clear. It does not appear, however, to be within the arm area and may possibly hold a relation to this area similar to that which the speech centre holds to the face area. The connection between the sensory and motor centres involved is probably made by association fibers which pass beneath the island of Reil. The sensory form of aphasia is capable of very considerable subdivision, and seems destined to yield results of much psychological importance. I would call attention to the fact that even Charcot's scheme is capable of extension and that aphasia or its intellectual equivalent would be in a deaf mute a lesion in the pathway formed between the centres for cutaneous sensibility, and that for the movement of the fingers in the arm area. That in other words any sensory centre may form the first link and any motor centre the second, and with this may be associated the intellectual life of the individual.

Of the processes occurring in nervous system, none perhaps contribute more to our anatomical information than that of degeneration. Degeneration is, however, a very complicated process. In the higher animals a section of nerve fibers within the central nervous system is not followed by reunion. The nature of the degeneration which follows such a section is dependent on a large number of conditions. To take an example which is related to the question of the representation of the cortex in the thalamus which we have just discussed: If in the rabbit the motor fibers coming from the cortex be sectioned in the crura, the distal portion alone degenerates. If the section of these same fibers be made between the internal capsule and the cortex, not only the distal but the proximal portion with its associated cell degenerate. The reason for this is by no means clear, but may be dependent on the connection of this region with the thalamus. The peripheral sensory nerves furnish an example, where the direction of the nerve impulse and direction of degeneration are dissimilar. In a very young animal separation of a motor nerve at the point where it emerges from the central nervous system is often followed by complete absorption,[2] of both nerve and cell within the nervous axis. If a somewhat greater length of nerve be left attached to the central portion, atrophy only, and not absorption occurs.

Whether the portion within the central axis is absorbed, because, in the first instance, too much has been removed, or because the part removed had a special nutritional value from its position, must be left undecided. But the ultimate disappearance of the residual portion seems

1 Trans. Cong. Am. Phys. and Surg. Vol. I. 1888.
2 Forel: Arch. of Psychiatrie B. XVIII, 1887.

in some way to depend on the struggle for existence among the cell elements in the growing organism. The failure of nerve fibers to unite within the central nervous system might be thought to have some relation to that curious interdependence between growth and specialization by which the one is exclusive of the other. But on the whole it appears as though the conditions of nutrition would offer the best explanation for what occurs.

LECTURE V.

Gentlemen : Permit me to call attention to certain facts which are somewhat aside from the direct line of the previous lectures. We have spoken as if cerebral localization were an absolute fact, and such is practically the case, when we confine our attention to man and the monkeys. If, however, we study cerebral localization in the vertebrate series, we find that it becomes less perfect as we pass downwards. In this matter, comparative anatomy is the starting point. I have here drawn the brains of a dog and of a bony fish. In these widely separated forms, the anatomists can identify the subdivisions of the encephalon, which are homologous. From the physiological side, the question of importance is, whether homologous portions of the nervous system have the same relative function throughout this series. Not many years ago, this question was answered in the affirmative. The experiments of Goltz upon dogs which led him to deny cerebral localization in man were based upon this assumption. We propose this evening to present evidence for the view that homologous portions of the nervous system have not the same relative function in the lower as in the higher vertebrates. The problem may be expressed in anatomical terms; if we attempt to depict the paths along which an impulse must pass from the time it enters until it leaves the central nervous system, we have some such scheme as this : A nerve fiber comes from the periphery, is interrupted by a cell in the spinal ganglion, and enters the cord by the dorsal cornua; it connects itself in some way with a central cell. This cell is in turn connected with a motor cell, from which a fiber passes out of the cord by the ventral root. An impulse thus enters by the sensory and passes out by the motor fibers. This pathway for an impulse occurs from one end of the nervous system to the other, and may be designated as the segmental pathway. On this segmental system, composed of the spinal ganglia, the central cells and those giving rise to the motor fibers, there is superposed a mass of material which is represented by the thalami and cerebral hemispheres. The exact relations of these two structures are not known. For our purpose, we may look upon them as forming a part of a long or central pathway, over which an incoming impulse may, in some cases, pass. It is necessary then to elaborate the diagram, and make it possible for a sensory impulse to pass by means of a central cell to the cortex, where, in all probability, another central cell is interpolated in its course; from there, it passes to the cell giving rise to efferent cortical fibers, and so back to the segmental motor nucleus. This latter is the long or central path, which may always be contrasted with the short or segmental path. The application of such a scheme to the question in hand is this : Where the segmental or short path is highly differentiated, we would expect but little control from the cerebral hemispheres; whereas, where the long or central path is highly differentiated, we would expect the function of the cerebral hemispheres to be important, and the segmental path unimportant.

To begin with a fundamental question : Are both paths always permeable ? This has been tested by the stimulation of the cerebral hemispheres in different orders of vertebrates, in which operation a certain portion of the long path was made to conduct the impulse, and this portion was thus shown to be permeable. The inference drawn is that if

permeable through a portion of its length, the path was permeable throughout its entire length. If we apply this test at different levels iu the vertebrate series, we find, as a general result, that the long path is always permeable, and, at the same time, we find that the differentiation in the cerebral hemispheres as indicated by the specialized character of the response, decreases from the higher to the lower orders; further, that centres where they can be made out, are less clearly circumscribed and subdivided in lower as compared with higher forms. In the very lowest forms examined, like the bony fish, the reaction to stimulation of the cerebrum is so crude and generalized that it is not distinguishable from reactions obtained through the segmental system. To determine whether the segmental path is permeable, the central path must be destroyed and reactions of the animal then observed. In general, it is found that an interrelation exists between the short and long path, of such a nature that the high development of the one is associated with the low development of the other. In the very highest vertebrates, it appears that in most parts of the cerebral system, the segmental paths are not permeable; but in animals below the dog, they certainly are permeable, and the complexity of reaction of which they are capable increases as we pass down the series. Before entering upon a description of the disturbances following interference with the cortex in mammals, such as the dog, I wish to refer to one immediate consequence of the operation. When a portion of the cortex is removed, a considerable number of the conducting fibers, which remain, undergo a secondary degeneration. In the process of dying, these residual fibres must get rid of their energy, and, in so doing, they cannot fail to influence the portions with which they are connected. It is apparently due to this disturbance that the transient phenomena, which act like inhibitions, arise. Turning now to the special cases, we shall commence with the experiments upon dogs, and before we have finished, I shall hope to have presented evidence for the statement that in the vertebrate series at its lowest limit, sensation and motion, spontaneity and choice are independent of the cerebral hemispheres, but that the dependence of these functions upon the hemispheres increases as we ascend in the series.

This figure[1] represents the brain of a dog with the right hemisphere removed. The animal lived more than a year after the last operation. The senses of sight, hearing, smell and taste were more or less impaired. The animal was a stupid creature, but the disturbances of motion were not to be seen until the two sides of the body were compared, when it was noticeable that motion was impaired upon the side opposite to the lesion. In the second diagram is represented a case where the attempt was made to cut out the frontal portions of both hemispheres. In addition to the intended removal, a secondary degeneration of the left occipital region occurred, which left in the end hardly more than one quarter of the hemispheres intact. The dog lived two and a half months after the last operation, and exhibited that ceaseless activity characteristics of dogs from which the frontal lobes have been removed. Voluntarily, it did not take food; but when food was given it, all the mechanical processes of chewing and swallowing were executed. The emotional sounds—barking, whining, growling, etc.—were appropriately used. At the time, when this animal was described, the operation was the most severe recorded for dogs. Since then Goltz has made a complete removal of both hemispheres[2] and the animal lived 51 days after the operation. This individual, for one reason or another, preserved no special senses. There was, however, no paralysis of any muscles, and the dermal sensations were everywhere present.

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1 Goltz Pflüger's Archiv., Bd., 42, 1888.
2 Neurologische Centralblatt, May, 1889.

As in the previous case, it required to be fed, but food placed well back in its mouth was properly chewed and swallowed. It moved about spontaneously, would stand upon its hind legs and walk in a co-ordinated manner. When hungry, it was restless; when satisfied, it slept. It could be awakened by a touch upon any part of its body, and, when so roused, it stretched after the manner of waking animals. From the foregoing, it will be seen that the loss of the hemispheres in the case of a dog is a pretty serious matter, but that a dog is still capable of living after such an operation, and preserves at least his dermal sensibility and considerable control over his muscles. As regards the special senses, we can only say that some remnant of vision may remain in a dog thus operated upon.

Christiani[1] experimented upon rabbits, and showed that when both hemispheres are removed, the rabbit can still see and hear, and retains its dermal sensibility. His experiments are open to the objection that the animals were not kept alive for more than two days. The operations, however, were perfect, and observations began immediateiy after the operation was performed. A rabbit is less disturbed by the loss of its hemispheres than a.dog, and it is particularly noticeable that hearing was retained. Birds also have been worked upon. Schrader[2] has done the best work upon pigeons. There is a wide difference in the intelligence and the relative value of the hemispheres among the various orders of birds. When a pigeon loses its hemispheres, it may at once begin to walk or will fly, when thrown into the air. In some cases they fall asleep, and are aroused only by hunger. Often, when placed upon the floor, such a bird will walk continuously until some obstacle stops it for a moment; when stopped, may fall asleep. The bird sees, and this spontaueity is due to the fact that it can see, for it roosts when it becomes dark. It can not feed itself, when its cerebral hemispheres are entirely removed, but the retention of a small portion will suffice for this purpose. It hears slightly, but will not heed the call of other birds. Taste and smell are difficult to demonstrate, even in normal birds. It will choose between two perches the one that is best suited to its purpose.

Reptiles have been experimented upon very little. We may pass at once, therefore, to frogs. A frog[3] is not deprived of all spontaneity, when the cerebral hemispheres alone are removed, that is, when the thalamus remains intact. The frog can jump and feed itself; it avoids obstacles and can see. It burys itself in the winter and awakes in the spring. In fact, the chief difference between the operated and normal frog is in a certain slowness and sluggishness in initiating any action. This discussion is complicated by the fact that the cerebral hemispheres consist of a basal ganglion, over which is spread a mantle. The mantle is functionally the more important in the higher animals, while it is of very little importance in the lowest vertebrates, and in the frog it may be removed without producing observable symptoms. In the bony fish, the mantle can be shown histologically to be non-nervous in structure, and whatever cerebral functions such an animal may have are associated with the basal ganglia. Cutting off all but the thalamus in a fish, there is no apparent loss of function, but the animal appears a trifle more rash. It can balance, swim, play, feed, distinguish between a worm and a piece of string, and select red wafers from an assortment of various colors thrown upon the water.[4]

We have some experiments upon the shark. If the brain is cut off in front of the thalamus, it can not feed, but retires to one side of the aquarium. The animal can see, but this is of no value to it. The same

1 Zur Physiologie des Gehirnes, 1885.
2 Pflüger's Archiv., Bd.. 44.
3 Schrader, Pflüger's Archiv.. Bd. 41.
4 Steiner. Functionen des Central nerven systems und ihre Phylogenese. Zwei e Abtheilung, 1888.

effect was produced when the olfactory lobes alone were cut off. The shark depends upon its sense of smell, and, since cutting of the cerebral hemispheres, deprived it of its most important sense, the effect, as we have seen, was serious. The relation of the dominant sense to the cerebral hemispheres must always be borne in mind in estimating the value of these experiments. For when the relation of this sense to the hemispheres is such that it must be necessarily injured, the effect will be far more serious than in those cases where it escapes injury. Witness the removal of the cerebral hemispheres in the shark, where the dominant sense—the olfactory—is necessarily injured, and the bony fish, in which the dominant sense—visual—is not disturbed.

The plasticity of the nervous system is shown by the following experiment:[1] If the cerebrum of a shark be cut out unsymmetrically, forced movements occur; the animal swims in a circle. If a shark be beheaded, the trunk swims in a straight line. If now an animal be taken and an unsymmetrical operation on the brain be performed, so as to obtain forced movements and the animal thereupon be beheaded, the trunk exhibits forced movements — like those before beheading — and which appear independent of any permanent contracture in the muscles. If, however, the time between the production of forced movement and the final beheading be less than eight or ten hours, forced movements in the trunk alone do not occur. It thus appears that a certain length of time is necessary to educate the spinal cord to perform this motion.

LECTURE VI.

Gentlemen: To-night I wish to give some account of the principal explanations which have been offered for phenomena of cerebral localization, and to indicate some of the points of contact between these phenomena and psychology. The explanations that have been offered have been mainly from physiological point of view, and have often lacked a good anatomical foundation. The phenomena which the various authors try to explain may be summarized as follows: The meaning of the movements that follows stimulation of certain portions of the cortex; the meaning of the loss of movement and sensation which follows removal of portions of the cortex; the significance of the permanent or transient character of those symptoms, and where transient, the interpretation of the gradual return of function. Further the degenerations following removal of portions of the cortex are to be explained. The explanations that have been offered have been strongly influenced by the bias of there authors, and differ from one another mainly in the emphasis which they put on similar facts. For example Schiff — Pflueger. XXX, 1883,—was strongly influenced by two previous conclusions, first, that nervous centres were not artificially excitable, and second, that dorsal columns of the spinal cord were the afferent paths for tactile impulses and lesion of them would cause an ataxic disturbance of locomotion. For him the true centres for sensation and motion were in the basal ganglia. The nerve fibers connecting these centres with the spinal cord formed an arch, the summit of which lay more or less close to the surface of the hemispheres. Stimulation of the cortex excited these sensory or aesthesodic fibers and brought about a reflex motion. Deep removal of the cortex injured the efferent or kinesodic fibers and gave rise to secondary descending degeneration. Return of function after injury was due to the taking up of the lost functions by those portions which remained intact. Schiff therefore emphasized the sensory side in his explanation. He looks upon Munk (Functionen der Grosshirnrinde p. 42) as the man nearest the truth in his explanation. Munk was struck by the fact that even outside of the so-called motor regions, stimulation of the

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1 Steiner. op. cit.

cortex gave rise to movements. These extra motor movements were particularly associated with the organs of special sense and were obtained from regions of the cortex which were later found to be the centres for these special senses. Since then each special sense appears to have definite movements associated with it, Munk was led to regard the motor region of the authors as a cortical centre for tactile sensation, in the wide sense of that term, and the motor responses here were to be compared with the motions of the eye upon stimulation of the visual, or of the ear or stimulation of the auditory region. In order to understand his theory of the restitution of function, we may regard his idea of the visual area, where he has worked out his views in detail. In the first place there is a detailed representation of the retina in the cortex. In the centre of this region are the cells which receive the simple sense impressions and around about this central portion are cells which store visual memories. Removal of the former causes absolute blindness, removal of the latter mind blindness or loss of visual memories. When restitution of function takes place it is by the education of the unoccupied cells in the surrounding regions. If all cells capable of this further development are removed, the animal becomes completely and permanently blind. Wundt has criticised the psychological side of this view with all needful severity and we shall see that the experiments of Goltz satisfactorily do away with any such theory of restitution. Goltz[1] came to the question fresh from the study of the spinal cord and apparently convinced of the general truth of Flourens' view, that there was no specialization of function in the hemispheres. In his general view of localization, Goltz is as far as any one from that which is demanded by the clinical medicine of to-day. At the same time he has contributed a large amount of experimental material which forms one of the most valuable chapters on this subject. In the first place he distinguished sharply between permanent and transient symptoms; the latter were brought about by inhibitions due to the secondary degenerations and other disturbances immediately following the operations. For him what is lost is permanently lost, so that restitution of function is never quite complete; but since each hemisphere is connected with both halves of the body, there may be an apparent return of function due to this fact. When both hemispheres are removed, he is forced to the segmental centres, as explained in the last lecture. In this controversy and especially against Goltz, it has been from time to time urged that the removal of a centre or a region was not complete and hence the functions were not abolished. Here and there some evidence appears that the physiological value of a small portion of the cortex may be out of all proportion to its actual size; but we can say nothing more on this point until it has been subjected to a direct experimental test. Hitzig[2] from the experimental side and Nothnagel[3] have emphasized the idea that disturbances of the muscle sense are the cause of the motor disturbance observed. To this view Bastian[4] has added the suggestion that the motor regions, besides being centres for the muscle sense, were also centres for obscure sensations—kinæsthesis—which informed us of the state of contraction of all the muscles of the body, and thus profoundly influenced the contraction of any given muscle. Bain and Wundt have added the sense of effort as a function of the efferent nerves; but this needs hardly to be taken into account, since Prof. James' criticism of their view. I mention these points to show how much vested interest there is in the various theories of the muscle sense, rather than to emphasize their import-

1 Verrichtungen des Grosshirns, 1881.
2 Untersuchungen 1874.
3 Virchow's Archiv. 1873.
4 Brain as an organ of mind, 1880.

ance for our present consideration. Brown-Sequard[1] has emphasized the idea of inhibition. For him both sides of the body are represented in each hemisphere of the brain and the usual symptoms which are taken to indicate motor and sensory centres in the cortex, are but the results of the inhibitory effect of lesions acting upon centres elsewhere situated. He attempts to support his view by clinical evidence to show that lesions almost anywhere in the cerebrum may produce similar symptoms. The method of proof is open to grave objections, and Brown-Sequard has few if any disciples. At the same time it is not impossible that some of the instances showing defect on the same side as the lesion may be true and explicable on the assumption of anomilies in the structure of the nervous system.

Without further entering upon the history of these views, I will at once proceed to give the explanation so far as it seems well supported by anatomy. Goltz has shown that the disturbances in locomotion and other movements cannot be properly explained by referring them to defects in sensation. For our general explanation we come back to the idea developed in the last lecture of a short segmental, or a long central path. To use the term sensory with regard to the afferent and motor with regard to the efferent portion of the central path is to a certain extent misleading. The terms are, however, in common use, and, if we can escape attaching too much value to them, are satisfactory. The course of the incoming impulse over the sensory path is yet to be made out. On leaving the cortex by the motor path its course seems comparatively clear. It is quite impossible to say whether in stimulating the cortex we stimulate the sensory cortical elements, and thus influence the motor ones or stimulate the motor directly. Any general scheme must also explain the restitution of function and this term may stand for a number of different events, especially in the higher animals. As Horsley[2] has shown the restitution of function in the case of hemorrhage into the internal capsule may be well associated with the resorption of the clot. Again the muscles of the phonation and mastication have in man a bilateral cortical representation so that as a rule these muscles on both sides of the body are represented in each hemisphere. Here of course the explanation of restitution is comparatively simple and it is this explanation which is also used in case of dogs with a single hemisphere. In fact bilateral representation appears to increase as we pass down the vertebrate series. There seems to be no evidence to show that when the arm is paralyzed through cortical lesion that there is here, in man at least, a restitution of function. But there is still another sort of restitution which differs mainly perhaps from the fact that it is more complex. I refer to such cases as those in which articulate speech is reacquired after destruction of the motor speech centre upon one side. About such an instance cluster a number of interesting problems. We know that as a rule for speech, both motor and sensory, the left hemisphere is the more important. Why this is the case is nevertheless not clear. That the important sensory and motor centres, which are in practice interrelated, should come to be in the same hemisphere, seems a natural result of the better anatomical connections between these centres on the same side of the brain; but whether in the determination of this side the motor or sensory element takes the lead, we cannot say. At the same time it would appear that both hemispheres of the brain share in the education even in those cases where the exercise seems to be limited to one side of the body. If this is so, then, the reacquisition of language by an adult, after loss of the motor centre for speech on one side, would perhaps be dependent upon this double education of the brain and the possibility of establishing connections between the sensory and mo-

1 Lancet, 1876, 1877.
2 Lancet, 1884.

tor centres in the hemisphere which had not been explicitly exercised.
This necessarily brings to our consideration the manner in which we are
to think of these associations as taking place. The long period of help-
lessness in the highest mammalia, the evident effect of training and ex-
ercise in the earliest years of life, would seem at first to point to the
establishment of new morphological relations as the result of functional
activity. A closer examination brings out a good deal of evidence against
this view. If functional superiority has a morphological basis, then the
left side of the brain should in most instances be the more largely de-
veloped.   In the average individual the difference in weight between the
two hemispheres lies within the errors of observation. We must consider
that, if a morphological change is brought about, it is practically the
same in both hemispheres. Further, in Laura Bridgman, the portions
of the hemispheres connected with her defective senses, though in some
instances slightly abnormal, were by no means lacking nor histological-
ly degenerate. So far as we know she had neither visual or sensory
memories. Considering growth and function as closely related, then the
growth in these portions of her hemispheres was certainly remarkable.
I am inclined to the view that the morphological characteristics of a brain
are very early fixed and that education has to do mainly with functional
developments hence, in the case we have been considering, the reacquisi-
tion of speech would depend on association paths which had already ex-
isted.   The sensory regions of the cortex have a peculiar interest and
value, for it seems on the one hand that the ideational of processes are
most closely linked with the sensory regions and that on the other hand
a single sensory region may serve as the basis for an intellectual life :
witness the mental development of the blind deaf-mutes. It may be
safely said that in acuteness, man is surpassed by some animal in the
case of every sense. Man is peculiar in the high development of several
senses and in the ability for cross-reference between them, so that, al-
though each principal sense at least would seem to be sufficient for a
basis of an intellectual existence, and thus each sensory region might be
considered a little brain, yet fullness of intellectual development would
appear to associate itself with a high simultaneous development.   On
this point the manifold symptoms of aphasia are most instructive.

NOTES ON MODELS OF THE BRAIN.

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1. The use of models of the brain as one means of instruction requires
no apology. In view of the interest which at present attaches to such
models, I have made a list of the principal ones with some annotations.
At my suggestion, Mr. T. L. Bolton has prepared a translation of the
description of the large brain-model manufactured by Auzoux. This
model appears to be, on the whole, the most instructive one, and, as the
original description was in French, the anatomical terms of which are,
as a rule, unfamiliar to our students, it was thought that such a transla-
tion of the description would make it more generally useful.

LIST OF MODELS.

1. Aeby's wire model of brain and cord : (Phantom des Faserverlaufes
im menschlichen Gehirn und Rückenmark von Prof. Dr. Chs. Aeby).
Made by F. R. Büchi, Meckaniker, Berne, Switzerland. Price, 500 francs.
Material, wire and cork. Shows the path of the fibres according to
Wernicke and is enlarged about six diameters. Useful from the fact
that, though giving the relations in three dimensions, it is transparent.
2. Auzoux (Mme. Ve Auzoux, 56 Rue de Vanguard, Paris). The
synthetic preparation of the brain (Cerveau de Texture de tres-grande